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Hybrid Anti-Rolling System for the Oceanographic Research Vessel "MIRAI"

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A new type anti-rolling device has been developed for the oceanographic research vessel "MIRAI" (8 672 GT). The hybrid system combines the advantages of both active and passive mechanisms ; the passive mechanism uses a moving 100 t weight on arc-shaped rails like the swing of the pendulum, and the active mechanism drives the mass with computer-controlled electric motors by real time sensing of ship rolling. This combination allows the device to be compact and to achieve high performance to reduce rolling during cruising and drifting under various loading conditions and sea states. The sea trial results have proved its performance and "MIRAI" is now in active use.

Key words: Ship, Research vessel, Deck machinery, Ship motion, Rolling motion reduction, Anti-rolling system, Anti-rolling tank, Response reduction

1. Introduction

Reducing ship rolling not only reduces seasickness but is also important for improving safety of workers on board, preventing damage to cargoes and improving residentiality. A new-type hybrid anti-rolling system has been developed by IHI to replace the existing systems such as fin stabilizer and anti-rolling tank utilized for various ships including passenger ships and car ferries. The new IHI system was installed on the 8 672 GT oceanographic research vessel "MIRAI", for the Japan Marine Science & Technology Center (JAMSTEC). Sea trial tests in open sea areas confirmed that the system performed as planned. The "MIRAI" conducts oceanographic research while drifting for a long time or sailing in rough sea areas with wave heights up to of 4 m, which requires a reduction in ship rolling. The "MIRAI" was delivered to the customer on September 29, 1997, after sea trials were conducted.

2. Development of hybrid anti-rolling system

A developmental project was launched by IHI to device equipment to reduce ship rolling by utilizing its technologies developed as damping devices for the main tower of bridges and high-rise buildings. The project consisted of research and development by adopting a hybrid system combining the electric motor drive (active mechanism) and the swing of pendulum (passive mechanism), a damping system most suited for a ship on which installation space and load of inboard power supply are limited. In 1993 and 1994, open sea trials were conducted using prototype devices with respective moving mass weight of 35 kg and 3.5 t and checked the control logic and anti-rolling performance. The trials confirmed the capability of the mechanism and that the ship rolling could be almost halved when the moving mass weight is about 1.5 to 2.0% of the ship's displacement[(1) ~ (3)].

3. Features of moving mass 100 t type hybrid anti-rolling system

3.1 Outline of the oceanographic research vessel "MIRAI" (Fig. 1)

The oceanographic research vessel ordered from JAMSTEC in January 1995 had the mission of conducting oceanographic research and research activities onboard in rough sea areas, which requires the reduction of ship

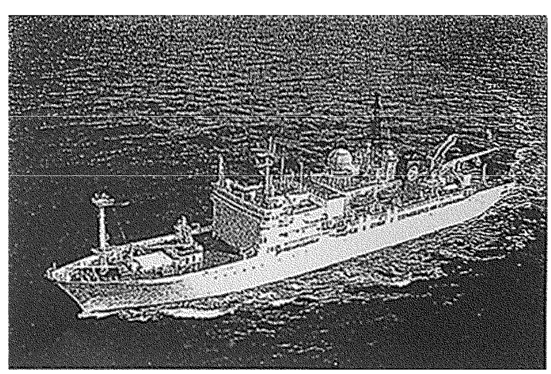


Fig. 1 Oceanographic research vessel "MIRAI"

rolling under various operating conditions. In addition to the oceanographic research works while cruising, there are such works as lowering onto the water and lifting an observation equipment when the ship is drifting and long-term towing of an underwater vehicle at a low speed. Since the ship follows a planned route called a "track" during the observation to acquire observation data in a wide sea area, the wind and wave direction are not always optimal for ship operation, and in some cases the ship is operated under severe conditions that cause ship rolling. IHI, therefore, tried to design an anti-rolling system to reduce ship rolling to about 50% in the SEASTATE 5 (equivalent to a wave height of 4 m), the sea condition (maximum) of the sea area where the observation works are carried out.

The principal particulars of the "MIRAI" are as follows.

Length b.p.	116.0 m
Breadth moulded	19.0 m
Depth moulded	10.5 m
Draft moulded	6.90/6.50 m (full load/designed)
Cruising speed	16 kt

3.2 Planning of anti-rolling system

(1) Outline of system

To maximize reduction of ship rolling, the system was provided at a higher position near the midship (**Fig. 2**). To secure the wider stroke of the moving mass, the rails on which the moving mass moves was designed as long as possible in the beam direction. By optimizating the arrangement of such equipment, etc., the target of rolling reduction could be achieved when the moving mass weight was made 100 t, about 1% of her displacement. The main specifications of the moving mass 100 t type hybrid anti-rolling system (**Fig. 3**) are as follows.

Moving mass weight	100 t
Moving mass amplitude	±4.0 m
Overall dimensions	14.5(L) × 4.6(W) × 4.3(H) m
Actuating motor	AC110 kW × 1 800 rpm × 3 units

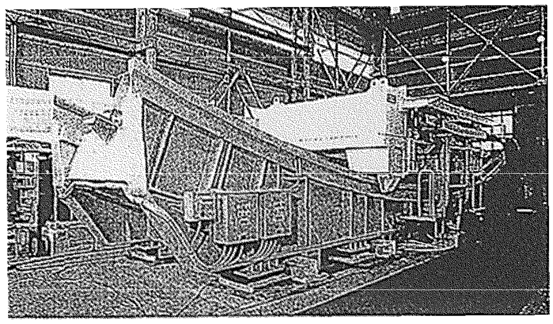


Fig. 3 Hybrid anti-rolling system

(2) Design conditions

The "MIRAI" conducts observation works under various sea conditions, including rough sea areas. Because the main engines can be operated selectively for cruising, very slow speed or intermediate speed, and the ship is operated along a specified observation course, the ship follows a fixed track regardless of wave direction. Under such various operating conditions, a high anti-rolling effect was required in any case, and a parametric study together with the various natural rolling periods was carried out. To investigate the specifications of the system components and the safety in strength, design conditions were applied exceeding the working conditions after clarifying the operating conditions of the system and the ship. As safety measures to protect the system, functions were added to enable the system to operate stably against sudden changes in wave height by automatically limiting the moving range of the mass when subjected to a large external force and by switching the sea mode on the control panel when it is predicted that the sea condition will deteriorate.

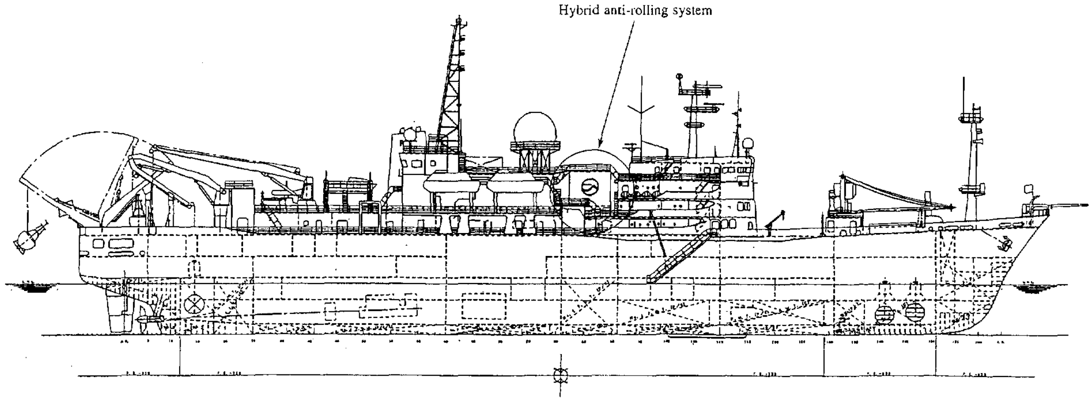


Fig. 2 Position of hybrid anti-rolling system

(3) Model test (**Fig. 4**) and sea trial test

To verify the availability of the theoretical calculation, a model basin test was carried out by using an experimental dummy of the anti-rolling system equipped on a scale model (1/36.25) of the vessel, to measure the hull motion when the system was operated and not operated under various conditions in regular and irregular waves, and to compare the results with the calculated values, so that a good coincidence was obtained. Prior to a final design of the 100 t mass type, test measurements were conducted outside Tokyo Bay by using a prototype of a 40 t moving mass which was installed on a test vessel (about 660 GT), to obtain data for the optimum control of the system and for designing safety devices in irregularly changing moment in an actual sea area. Analytical studies were also conducted under the same sea conditions under which the tests were conducted and confirmed the availability of the simulation method by comparing the results with the measurement results.

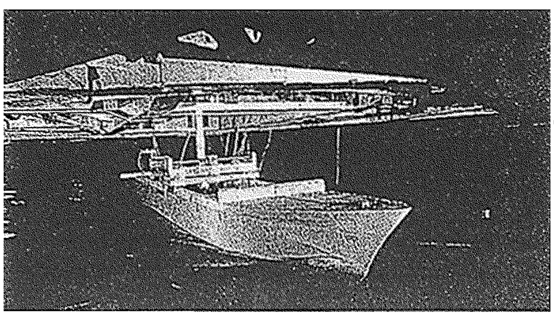


Fig. 4 Model basin test

4. Results of sea trial test

4.1 Anti-rolling effect confirming test

From May 9 to 12, 1997, after the anti-rolling system was installed on the "MIRAI", the anti-rolling performance was checked by measuring ship rolling when the system was operated and not operated in a wave direction series test while the ship was drifting and sailing at normal speed (16 kt) (**Table 1**).

(1) Test items
- Case ①, ③. Beam sea test during ship drifting
- Case ② Wave direction series test

(2) Test conditions
- Date of testing May 9 to 12, 1997
- Test sea area About 30 miles north-northeast of Hachijo Island
- Sea condition Significant wave height 3.5 to 5.0 m
  Wave period About 6 to 8 s
  Wind velocity 11 to 14 m/s
  Wind direction North-northeast
- Ship condition Mean draft 6.3 m
  Natural rolling period 13.1 s

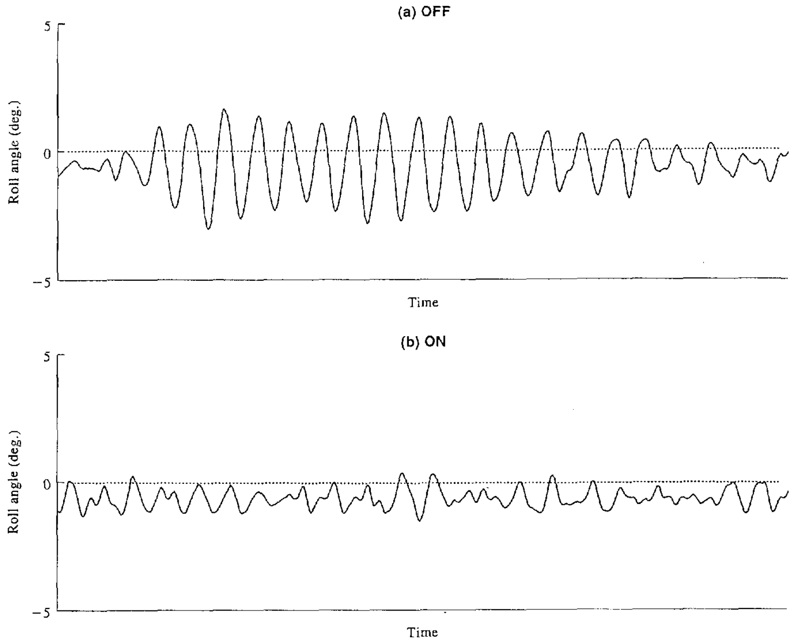
Fig. 5 and **Fig. 6** show the time history response of the roll angle measured when the system was operated and not operated in cases ①-1 and ②-2 and cases ②-3 and ②-4, respectively. On the test day, the sea conditions consisted mainly of wind and waves because it was just after the passing of a depression, and the wave period was shorter in comparison with the natural period of ship rolling. In the following sea or quartering sea (i.e. angle of encounter: 45°) of cases ②-2 and ②-4, the period of encounter with waves becomes close to the

Table 1 Summary table of trial test

Case \ Item	Test condition			Sea conditions		Roll angle			
	Ship speed (kt)	Relative wave direction	Anti-rolling system (ON/OFF)	Significant wave height (m)	Wave encounter period (s)	Peak value (deg.)	Significant value (deg.)	Rolling attenuation ratio* (%) Peak value	Rolling attenuation ratio* (%) Significant value
①-1	0	Beam sea	OFF	3.5	7.1	3.8	2.0	36	15
①-2			ON	3.9	7.3	2.7	1.9		
②-1	16	Following sea	OFF	6.3	11.8	5.7	3.7	55	31
②-2			ON	5.7	12.4	2.9	2.3		
②-3		Quartering sea	OFF	5.2	11.7	7.8	4.4	42	38
②-4			ON	5.5	12.4	4.8	2.9		
②-5		Beam sea	OFF	4.2	7.8	5.1	3.5	20	34
②-6			ON	4.0	7.2	3.9	2.2		
②-7		Bow sea	OFF	3.5	6.9	2.8	1.7	14	18
②-8			ON	3.8	7.2	2.6	1.5		
②-9		Head sea	OFF	3.4	6.2	3.2	2.1	31	41
②-10			ON	3.6	6.5	2.3	1.3		
③-1	0	Beam sea	OFF	1.3	6.3	2.4	1.5	50	59
③-2			ON	1.3	6.4	1.2	0.6		

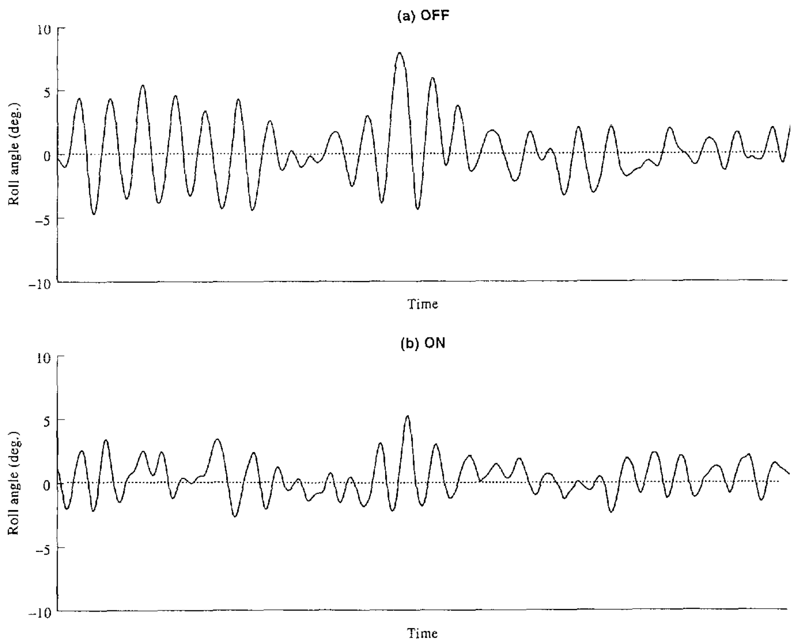
(Note) * : Rolling attenuation ratio $= \left(1 - \frac{\text{Rolling amplitude with system turned on}}{\text{Ditto with system shut off}}\right) \times 100$ (%)

Rolling attenuation ratio is calculated by using corrected rolling angle with significant wave height as measured at each test



(Note) Time history responses were measured for 300 s.

Fig. 5 Time history (roll) : drifting in beam sea



(Note) Time history responses were measured for 300 s.

Fig. 6 Time history (roll) : sea keeping in quartering sea

natural period of the ship, showing a higher anti-rolling effect in comparison with other cases.

4.2 Function test

During the sea trials on May 7 ~ 12 and August 20 ~ 24, 1997, tests were carried out on safety functions, etc. of the system. The tests were conducted in the form of inboard noise/vibration measurement, conduction noise/radiation noise measurement, and current/voltage fluctuation measurement when the system was operated and confirmed that other equipment inboard and residentiality were not adversely affected. During other series of sea trial operations carried out in the period of June 24 to July 1, 1997, a rough sea condition (significant wave height : about 8 m, maximum wave height : about 17 m) was experienced during the passage of a typhoon. In such circumstances, the system was continuously operated and it was able to check the decrease in steerability by reducing the ship motion. In a storm when the ship motion is large, the main engine is decelerated, but since the anti-rolling effect can be obtained with this system regardless of the ship speed, it was found that it effectively worked for the maneuvering performance as well.

5. Conclusion

To achieve the oceanographic research mission of the "MIRAI", a system that can demonstrate the anti-rolling performance under a wide range of sailing conditions including ship drifting and low-speed sailing was developed, and its anti-rolling performance was confirmed as follows.

(1) It was confirmed that the hybrid anti-rolling system could demonstrate in open sea areas the anti-rolling effect to reduce the ship rolling about 50% in comparison with non-operation of the system at the wave height of 4 m, the initial target.

(2) The anti-rolling effect can be obtained when the ship is drifting, and during decelerated operation, and when the ship speed is decreased due to the head sea, etc. which could not be coped with by the conventional fin stabilizer (active system). The anti-rolling effect was also obtained even in the case of a wave encounter period that departed from the natural period of the ship in which it was difficult to reduce the rolling with a passive system such as anti-rolling tank.

(3) The hull rolling response predicted by the simulation method, etc. showed a good coincidence with the measurement results in open sea areas and the motion simulation method of the ship, equipped with the anti-rolling system, was established.

REFERENCES

(1) M. Oikawa, Y. Koike, et al.: Study and At-sea Experiment on Actively Controlled Anti-Rolling System, Journal of The Society of Naval Architects of Japan Vol. 174 1993 pp.217–223

(2) Y. Koike, K. Yoshikai, et al.: Study and At-sea Experiment on Actively Controlled Anti-Rolling System, Journal of The Society of Naval Architects of Japan Vol. 176 1994 pp.137–143

(3) Y. Koike, E. Hiroshige, et al.: Development of Hybrid Anti-Rolling System for Ships and Sea Experiments, Ishikawajima-Harima Engineering Review Vol. 35 No. 6 Nov. 1995 pp.395–399

(4) K. Tanida: The Research and Development Trends of Active Control Techniques for Reducing Ship Motions at Sea, Bulletin of The Society of Naval Architects of Japan Vol. 800 1996 pp.119–124

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